Massachusetts Institute of Technology
Department of Physics Center for Space Research



# FINAL REPORT

NASA Grant: NAG691
"Studies of HEAO-MC Identified Objects with ASTRO-C"
December 22, 1993
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MIT Center for Space Research

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Objectives: It was proposed to carry out x-ray observations with Astro-C (later named *Ginga*) in order to study the characteristics of several sources that had been identified as part of our HEAO-1 modulation-collimator survey of the x-ray sky.

History of Contract

12/1/87: $37K awarded on basis of Proposal "Studies of HEAO-MC Identified Objects with Astro-C., dated Apl. 1987. Observing time awarded for H0538+608 and H2106–099.
9/6/88: $4K awarded to provide Macintosh Computer for use in Japan by Americans on the Ginga program
12/88: $57K awarded for observations of PKS 0558–504 and H0709–360, based on proposal dated May 27, 1988 "Ginga Studies of HEAO-MC Identified Objects FY1989"
11/90: $47K awarded for continuing analyses of data obtained on above four sources.
Total Award: $144.810.
9/91: No cost extension - 12 mos.
9/92: No cost extension - 12 mos.
9/30/93: Expiration.

Observations and Results:

The following observations were carried out (or attempted) with Ginga.

1. H0538+608 (AM Her type with aperiodic variability).
A Ginga observartion was obtained in Feb. 1988. This observation was the linchpin of a major multifrequency campaign that included two different types of optical data (intensity monitoring with 5-min. resolution and spectroscopy). Together these data made possible a detailed modeling of this unusual source. AM-Her type objects are binary systems consisting of two stars with a very large magnetic field emanating from the white dwarf. Most such systems exhibit synchronous rotation of the orbit and white dwarf and very regular orbital variations. This system is highly unusual in that its x ray and optical variations are highly aperiodic - in addition to the periodic variations observed. The multifrequency observations demonstrated that the rotation is most likely not synchronous by only about 1%, which could explain the aperiodic behavior. A complete geometrical model of the system was developed by Silber. This formed a major part of his PhD thesis (MIT 1992) and resulted in two publications (Ishida et al. and Silber et al.) in Astrophysical Journal.

2. PKS 0558–504 (quasar with steep x-ray spectrum and fast x-ray flare).
This quasar was observed with Ginga in Nov. 1989. The motivation was the steep x-ray spectrum that had been observed in a previous x-ray observation with EXOSAT. It has been suggested that this spectrum could be the high-frequency end of radiation from an accretion disk around the postulated massive black hole in the object. The Ginga observations reached to higher energies and thus could explore whether there was an underlying flatter spectrum. Observations were taken concurrently with IUE and optical observations. The observations yielded two major results which have resulted in two

papers, one in print (Nature) and one in final preparation for Astrophysical Journal. This work formed a significant part of the PhD thesis of Dr. Bruce Grossan (1992).

a. A spectacular rapid and large x-ray flare was detected in the Ginga data. The x-ray flux almost doubled in only three minutes. This established a record value for the rate of change of luminosity. This increase was so rapid and large that it violated a basic physical limit for an isotropic non-relativistic process. This demonstrates that the x-ray emission (from the flare at least) must be due to relativistic beaming. This is the first demonstration of such beaming in such an 'ordinary' emission-line quasar.

b. The spectrum from UV to x ray was compared to earlier data (1983-88). It was found that the optical and UV data from the two data sets matched extremely well, within ~3% whereas the Ginga x-ray flux was lower than the earlier EXOSAT data by a factor of 2.3. This demonstrates that the x ray emission appears to be decoupled, at least in part, from the optical-UV regions.

c. The Ginga x-ray spectrum was also found to be steep compared to normal AGN (index ~1.1 vs. 0.7), but not quite as steep as the EXOSAT data (index 1.3). An excess flux was found in the Ginga data at low energies (1-2 keV). This could, in principle, be the high-energy tail of emission from an accretion disk. The Ginga data thus do not contradict the accretion disk model. The steep spectrum (index ~1.1carries on to 15 keV, the highest energy known for such a steep spectrum.

3. H2106–099 (Variable Seyfert galaxy) with weak blue bump.
This object showed marked x-ray variability in the HEAO-1 data (factor of 3 in 6 months) and exhibited high-excitation lines in optical data. This makes it a rather unusual object worthy of further study. Ginga observations were obtained on two occasions separated by 5 days, on 18 and 23 May 1988, and concurrent (or nearly concurrent) observartions in the radio, optical (spectra and CCD photometry) and UV were obtained. The source was in a faint state and x-ray statistics were limited so variability could only be measured on the 5-day time scale. X-ray variability was less than ~40%, or much less than that detected with HEAO. The source was clearly in a quiescent state during the Ginga observations. The UV variability was negligible but the optical variability on 1-year time scales is ~30%.

Our IUE observations of this source exhibited substantial absorption at the 217.5 nm feature of the extinction curve (cross section vs wavelength). This permitted an estimate of the total extinction, $E$ (B–V) = 0.17 mag. of which only 0.10 mag is due to our Galaxy. The balance is attributed to the host galaxy of the AGN. This result permitted the determination of a reliable instrinsic (unreddened) spectrum of the AGN. This showed that this AGN intrinsically has a 'weak' blue bump. Since 'blue bumps' are common in many AGN, this is an important result. In one scenario this would indicate the character or extent of an accretion disk around the massive black hole. Previous weak-bump cases could have been brought about by uncertain reddening between the AGN and Earth. These several results are reported in the PhD thesis of Dr. Grossan and in a paper by Grossan now being reviewed by coauthors.

4. 1H0709–360 (Cataclysmic variable in period gap).
This object held high promise because of its (optical) orbital period of 2.444 hours fell well within the well known 2-3 h gap of periods for such binary systems. Other than the original HEAO-1 observations there had been no detailed x-ray observations. Unfortunately, this source was not visible in the Ginga data. Another nearby source (probably an RS CVn object) was in the field of view; it exhibited pronounced flaring. A scan over the source region did not show a source in the position of the optical object